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APPLICATION FOR UNITED STATES PATENT

FOR

SUBSEA CHEMICAL INJECTION UNIT FOR ADDITIVE INJECTION AND MONITORING SYSTEM FOR OILFIELD OPERATIONS

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application takes priority from U.S. Provisional Application serial number 60/403,445 filed August 14, 2002.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to oilfield operations and more particularly to a subsea chemical injection and fluid processing systems and methods.

2. Background of the Art

Conventional offshore production facilities often have a floating or fixed platforms stationed at the water's surface and subsea equipment such as a well head positioned over the subsea wells at the mud line of a seabed. The production wells drilled in a subsea formation typically produce fluids (which can include one or more of oil, gas and water) to the subsea well head. This fluid (wellbore fluid) is carried to the platform via a riser or to a subsea fluid separation unit for processing. Often, a variety of chemicals (also referred to herein as "additives") are introduced into these production wells and processing units to control, among other things, corrosion, scale, paraffin, emulsion, hydrates, hydrogen sulfide, asphaltenes, inorganics and formation of other harmful chemicals. In offshore oilfields, a single offshore platform (e.g., vessel, semi-submersible or fixed system) can be used to supply these additives to several producing wells.

The equipment used to inject additives includes at the surface a chemical supply unit, a chemical injection unit, and a capillary or tubing (also referred to herein as "conductor line") that runs from the offshore platform through or along the riser and into the subsea wellbore. Preferably, the additive injection systems supply precise amounts of additives. It is also desirable for these systems to periodically or continuously monitor the actual amount of the additives being dispensed, determine the impact of the dispersed additives, and vary the amount of dispersed additives as needed to maintain certain desired parameters of interest within their respective desired ranges or at their desired values.

In conventional arrangements, however, the chemical injection unit is positioned at the water surface (e.g., on the offshore platform or a vessel), which can be several hundred to thousands of feet) from the subsea wellhead. Moreover, the tubing may direct the additives to produced fluids in the wellbores located hundreds or thousands of feet below the seabed floor. The distance separating the chemical injection unit and the locus of injection activity can reduce the effectiveness of the additive injection process. For example, it is known that the wellbore is a dynamic environment wherein pressure, temperature, and composition of formation fluids can continuously fluctuate or change. The distance between the surface-located chemical injection unit and the subsea environment introduces friction losses and a lag between the sensing of a given condition and the execution of measures for addressing that condition. Thus, for instance, a conventionally located chemical injection unit may inject chemicals to remedy a condition that has since changed.

The present invention addresses the above-noted problems and provides an enhanced additive injection system suitable for subsea applications.

SUMMARY OF THE INVENTION

This invention provides a system and method for deployment of chemicals or additives in subsea oilwell operations. The chemicals used prevent or reduce build up of harmful elements, such as paraffin or scale and prevent or reduce corrosion of hardware in the wellbore and at the seabed, including pipes and also promote separation and/or processing of formation fluids produced by subsea wellbores. In one aspect, the system includes one or more subsea mounted tanks for storing chemicals, one or more subsea pumping systems for injecting or pumping chemicals into one or more wellbores and/or subsea processing units(s), a system for supplying chemicals to the subsea tanks, which may be via an umbilical interfacing the subsea tanks to a surface chemical supply unit or a remotely-controlled unit or vehicle that can either replace the empty subsea tanks with chemical filled tanks or fill the subsea tanks with the chemicals. The subsea tanks may also be replaced by any other conventional methods. The surface and subsea tanks may include multiple compartments or separate tanks to hold different chemicals which can be deployed into wellbores at different or same time. The subsea chemical injection unit can be sealed in a water-tight enclosure. The subsea chemical storage and injection system decreases the viscosity problems related to pumping chemicals from the surface through umbilical capillary tubings to a subsea installation location that may in some cases be up to 20 miles from the surface pumping station.

The system includes sensors associated with the subsea tank, the subsea pipes carrying the produced fluids, the wellbore, the umbilical and the surface facilities. The surface to subsea interface may use fiber optic cables to monitor the condition of the umbilical and the lines and provide chemical, physical and environmental data, such as chemical composition, pressure, temperature, viscosity etc. Fiber optic sensors along with conventional sensors may also be utilized in the system wellbore. Other suitable sensors to determine the chemical and physical characteristics of the chemical being injected into the wellbore and the fluid extracted from the wellbore may also be used. The sensors may be distributed throughout the system to provide data relating to the properties of the chemicals, the wellbore produced fluid, processed fluid at subsea processing unit and surface unit and the health and operation of the various subsea and surface

equipment.

The surface supply units may include tanks carried by a platform or vessel or buoys associated with the subsea wells. Electric power at the surface may be generated from solar power or from conventional power generators. Hydraulic power units are provided for surface and subsea chemical injection units. Controllers at the surface alone or at subsea locations or in combination control the operation of the subsea injection system in response to one or parameters of interests relating to the system and/or in response to programmed instructions. A two-way telemetry system preferably provides data communication between the subsea system and the surface equipment. Commands from the surface unit are received by the subsea injection unit and the equipment and controllers located in the wellbores. The signals and data are transmitted between and/or among equipment, subsea chemical injection, fluid processing units, and surface equipment. A remote unit, such as at a land facility, may also be provided. The remote location then is made capable of controlling the operation of the chemical injection units of the system of the present invention.

In one embodiment, the present invention provides a subsea additive injection system for treating formation fluids. In one mode, the system injects, monitors and controls the supply of additives into fluids recovered through subsea production wellbores. The system can include a surface facility having a supply unit for supplying additives to a chemical injection unit located at a subsea location.

The chemical injection unit includes a pump and a controller. The pump supplies, under pressure, a selected additive from a chemical supply unit into the subsea wellbore via a suitable supply line. In one embodiment, one or more additives are pumped from an umbilical disposed on the outside of a riser extending to a surface facility. In another embodiment, the additives are supplied from one or more subsea tanks. The controller at a seabed location determines additive flow rate and controls the operation of the pump according to stored parameters in the controller. The subsea controller adjusts the flow rate of the additive to the wellbore to achieve the desired level of chemical additives.

The system of the present invention may be configured for multiple production wells. In one embodiment, such a system includes a separate pump, a fluid line and a subsea controller for each subsea well. Alternatively, a suitable

common subsea controller may be provided to communicate with and to control multiple wellsite pumps via addressable signaling. A separate flow meter for each pump provides signals representative of the flow rate for its associated pump to the onsite common controller. The seabed controller at least periodically polls each flow meter and performs the above-described functions. If a common additive is used for a number of wells, a single additive source may be used. A single or common pump may also be used with a separate control valve in each supply line that is controlled by the controller to adjust their respective flow rates. The additive injection of the present invention may also utilize a mixer wherein different additives are mixed or combined at the wellsite and the combined mixture is injected by a common pump and metered by a common meter. The seabed controller controls the amounts of the various additives into the mixer.

The additive injection system may further include a plurality of sensors downhole which provide signals representative of one or more parameters of interest. Parameter of interest can include the status, operation and condition of equipment (e.g., valves) and the characteristics of the produced fluid, such as the presence or formation of sulfites, hydrogen sulfide, paraffin, emulsion, scale, asphaltenes, hydrates, fluid flow rates from various perforated zones, flow rates through downhole valves, downhole pressures and any other desired parameter. The system may also include sensors or testers that provide information about the characteristics of the produced fluid. The measurements relating to these various parameters are provided to the wellsite controller which interacts with one or more models or programs provided to the controller or determines the amount of the various additives to be injected into the wellbore and/or into a subsea fluid treatment unit and then causes the system to inject the correct amounts of such additives. In one aspect, the system continuously or periodically updates the models based on the various operating conditions and then controls the additive injection in response to the updated models. This provides a closed-loop system wherein static or dynamic models may be utilized to monitor and control the additive injection process. The additives injected using the present invention are injected in very small amounts. Preferably, the flow rate for an additive injected using the present invention is at a rate such that the additive is present at a concentration of from about 1 parts per million (ppm) to

about 10,000 ppm in the fluid being treated.

The surface facility supports subsea chemical injection and monitoring activities. In one embodiment, the surface facility is an offshore rig that provides power and has a chemical supply that provides additives to one or more injection units. This embodiment includes an offshore platform having a chemical supply unit, a production fluid processing unit, and a power supply. Disposed outside of the riser are a power transmission line and umbilical bundle, which transfer electrical power and additives, respectively, from the surface facility to the subsea chemical injection unit. The umbilical bundle can include metal conductors, fiber optic wires, and hydraulic lines.

In another embodiment, the surface facility includes a relatively stationary buoy and a mobile service vessel. The buoy provides access to an umbilical adapted to convey chemicals to the subsea chemical injection unit. In one embodiment, the buoy includes a hull, a port assembly, a power unit, a transceiver, and one or more processors. The umbilical includes an outer protective riser, tubing adapted to convey additives, power lines, and data transmission lines having metal conductors and/or fiber optic wires. The power lines transmit energy from the power unit to the chemical injection unit and/or other subsea equipment. In certain embodiments, the transceiver and processors cooperate to monitor subsea operating conditions via the data transmission lines. Sensors may be positioned in the chemical supply unit, the production fluid processing unit, and the riser. The signals provided by these sensors can be used to optimize operation of the chemical injection unit. The service vessel includes a surface chemical supply unit and a docking station or other suitable equipment for engaging the buoy and/or the port. During deployment, the service vessel visits one or more buoys, and, pumps one or more chemicals to the chemical injection unit via the port and umbilical.

Examples of the more important features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood and in order that the contributions they represent to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed understanding of the present invention, reference should be made to the following detailed description of the one mode embodiments, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

Figure 1 is a schematic illustration of an offshore production facility having an additive injection and monitoring system made according to one embodiment of the present invention;

Figure 2 is a schematic illustration of a additive injection and monitoring system according to one embodiment of the present invention;

Figure 3 shows a functional diagram depicting one embodiment of the system for controlling and monitoring the injection of additives into multiple wellbores, utilizing a central controller on an addressable control bus;

Figure 4 is a schematic illustration of a wellsite additive injection system which responds to in-situ measurements of downhole and surface parameters of interests according to one embodiment of the present invention;

Figure 5A is a schematic illustration of a surface facility having a platform according to one embodiment of the present invention; and

Figure 5B is a schematic illustration of a surface facility having a service vessel and buoy made according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring initially to **Figure 1**, there is schematically shown a chemical injection and monitoring system **100** (hereafter "system **100**") made in accordance with the present invention. The system **100** may be deployed in conjunction with a surface facility **110** located at a water's surface **112** that services one or more subsea production wells **60** residing in a seabed **116**. Conventionally, each well **60** includes a well head **114** and related equipment positioned over a wellbore **118** formed in a subterranean formation **120**. The well bores **118** can have one or more production zones **122** for draining hydrocarbons from the formation **120** ("produced fluids" or "production fluid"). The production fluid is conveyed to a surface collection facility (e.g., surface facility **110** or separate structure) or a subsea collection and/or processing facility **126** via a line

127. The fluid may be conveyed to the surface facility **110**-via a line **128** in an untreated state or, preferably, after being processed, at least partially, by the production fluid-processing unit **126.**

The system **100** includes a surface chemical supply unit **130** at the surface facility **110**, a single or multiple umbilicals **140** disposed inside or outside of the riser **124**, one or more sensors **S**, a subsea chemical injection unit **150** located at a remote subsea location (*e.g.*, at or near the seabed **116**), and a controller **152**. The sensors **S** are shown collectively and at representative locations; *i.e.,* water surface, wellhead, and wellbore. In some embodiments, the system **100** can include a power supply **153** and a fluid-processing unit **154** positioned on the surface facility **110**. The umbilical **140** can include hydraulic lines **140h** for supplying pressurized hydraulic fluid, one or more tubes for supplying additives **140c**, and power/data transmission lines **140b** and **140d** such as metal conductors or fiber optic wires for exchanging data and control signals. The chemical injection unit can be sealed in a water-tight enclosure.

During production operations, in one embodiment the surface chemical supply unit **130** supplies (or pumps) one or more additives to the chemical injection unit **150**. The surface chemical supply unit **130** may include multiple tanks for storing different chemicals and one or more pumps to pump chemicals to the subsea tank **131**. This supply of additives may be continuous. Multiple subsea tanks may be used to store a pre-determined amount of each chemical. These tanks **131** then are replenished as needed by the surface supply unit **130**. The chemical injection unit **150** selectively injects these additives into the production fluid at one or more pre-determined locations. In a one mode of operation, the controller **152** receives signals from the sensors **S** regarding a parameter of interest which may relate to a characteristic of the produced fluid. The parameters of interest can relate, for example, to environmental conditions or the health of equipment. Representative parameters include but are not limited to temperature, pressure, flow rate, a measure of one or more of hydrate, asphaltene, corrosion, chemical composition, wax or emulsion, amount of water, and viscosity. Based on the data provided by the sensors **S**, the controller **152** determines the appropriate amount of one or more additives needed to maintain a desired or pre-determined flow rate or other operational criteria and alters the operation of the chemical injection unit **150** accordingly. A surface controller

152S may be used to provide signals to the subsea controller **152** to control the delivery of additives to the wellbore **118** and/or the processing unit **126**.

Referring now to **Figure 2**, there shown a schematic diagram of a subsea chemical injection system **150** according to one embodiment of the present invention. The system **150** is adapted to inject additives **13a** into the wellbore **118** and/or into a subsea surface treatment or processing unit **126.** The system **150** is further adapted to monitor pre-determined conditions (discussed later) and alter the injection process accordingly. The wellbore **118** is shown as a production well using typical completion equipment. The wellbore **118** has a production zone **122** that includes multiple perforations **54** through the formation **120.** Formation fluid **56** enters a production tubing **59** in the well **118** via perforations **54** and passages **62**. A screen **58** in the annulus **51** between the production tubing **59** and the formation **120** prevents the flow of solids into the production tubing **59** and also reduces the velocity of the formation fluid entering into the production tubing **59** to acceptable levels. An upper packer **64a** above the perforations **54** and a lower packer **64b** in the annulus **51** respectively isolate the production zone **122** from the annulus **51a** above and annulus **51b** below the production zone **122.** A flow control valve **66** in the production tubing **59** can be used to control the fluid flow to the seabed surface **116**. A flow control valve **67** may be placed in the production tubing **62** below the perforations **54** to control fluid flow from any production zone below the production zone **122.**

A smaller diameter tubing **68**, may be used to carry the fluid from the production zones to the subsea wellhead **114**. The production well **118** usually includes a casing **40** near the seabed surface **116.** The wellhead **114** includes equipment such as a blowout preventor stack **44** and passages **14** for supplying fluids into the wellbore **118.** Valves (not shown) are provided to control fluid flow to the seabed surface **116**. Wellhead equipment and production well equipment, such as shown in the production well **118**, are well known and thus are not described in greater detail.

Referring still to **Figure 2**, in one aspect of the present invention, the desired additive **13a** is injected into the wellbore **118** via an injection line **14** by a suitable pump, such as a positive displacement pump **18** ("additive pump"). In one aspect, the additive **13a** flows through the line **14** and discharges into the production tubing **60** near the production zone **122** via inlets or passages **15**.

The same or different injection lines may be used to supply additives to different production zones. In **Figure 2**, line **14** is shown extending to a production zone below the zone **122.** Separate injection lines allow injection of different additives at different well depths. The additives **13a** may be supplied from a tank **131** that is periodically filled via the supply line **140**. Alternatively, the additives **13a** may be supplied directly from the surface chemical supply **130** via supply line **140c**. The tank **131** may include multiple compartments and may be replaceable tanks which is periodically replaced. A level sensor S_L can provide to the controller **152** or **152S** (Fig. 1) indication of the additive remaining in the tank **131**. When the additive level falls below a predetermined level, the tank is replenished or replaced. Alternatively a remotely operated vehicle **700** ("ROV") may be used to replenish the tank via feed line **140**. The ROV **700** attaches to the supply line and replenishes the tank **131**. Other conventional methods may be used to replace tank **131**. Replaceable tanks are preferably quick disconnect types (e.g., mechanical, hydraulic, etc.). Of course, certain embodiments can include a combination of supply arrangements.

In one embodiment, a suitable high-precision, low-flow, flow meter **20** (such as gear-type meter or a nutating meter) measures the flow rate through line **14** and provides signals representative of the flow rate. The pump **18** is operated by a suitable device **22** such as a motor. The stroke of the pump **18** defines fluid volume output per stroke. The pump stroke and/or the pump speed are controlled, e.g., by a 4 - 20 milliamperes control signal to control the output of the pump **18**. The control of air supply controls a pneumatic pump. Any suitable pump and monitoring system may be used to inject additives into the wellbore **118**.

In one embodiment of the present invention, a seabed controller **80** controls the operation of the pump **18** by utilizing programs stored in a memory **91** associated with the subsea controller **80**. The subsea controller **80** preferably includes a microprocessor **90**, resident memory **91** which may include read only memories (ROM) for storing programs, tables and models, and random access memories (RAM) for storing data. The microprocessor **90** utilizes signals from the flow meter **20** received via line **21** and programs stored in the memory **91** to determine the flow rate of the additive. The wellsite controller **80** can be programmed to alter the pump speed, pump stroke or air supply to deliver the

desired amount of the additive **13a**. The pump speed or stroke, as the case may be, is increased if the measured amount of the additive injected is less than the desired amount and decreased if the injected amount is greater than the desired amount.

The seabed controller **80** preferably includes protocols so that the flow meter **20**, pump control device **22**, and data links **85** made by different manufacturers can be utilized in the system **150**. In the oil industry, the analog output for pump control is typically configured for 0-5 VDC or 4-20 milliampere (mA) signal. In one mode, the subsea controller **80** can be programmed to operate for such output. This allows for the system **150** to be used with existing pump controllers. A power unit **89** provides power to the controller **80**, converter **83** and other electrical circuit elements. The power unit **89** can include an AC power unit, an onsite generator, and/or an electrical battery that is periodically charged from energy supplied from a surface location. Alternatively, power may be supplied from the surface via a power line disposed along the riser **124** (discussed in detail below).

Still referring to **Figure 2**, the produced fluid **69** received at the seabed surface **116** may be processed by a treatment unit or processing unit **126.** The seabed processing unit **126** may be of the type that processes the fluid **69** to remove solids and certain other materials such as hydrogen sulfide, or that processes the fluid **69** to produce semi-refined to refined products. In such systems, it is desired to periodically or continuously inject certain additives. Thus, the system **150** shown in **Figure 1** can be used for injecting and monitoring additives **13b** into the processing unit **126.** These additives may be the same or different from the additives injected into the wellbore **118**. These additives **13b** are suitable to process the produced wellbore fluid before transporting it to the surface. In configuration of **Fig. 2**, the same chemical injection unit may be utilized to pump chemicals in multiple wellbores, subsea pipelines and/or subsea processing units.

In addition to the flow rate signals **21** from the flow meter **20**, the seabed controller **80** may be configured to receive signals representative of other parameters, such as the rpm of the pump **18**, or the motor **22** or the modulating frequency of a solenoid valve. In one mode of operation, the wellsite controller **80** periodically polls the meter **20** and automatically adjusts the pump controller

22 via an analog input **22a** or alternatively via a digital signal of a solenoid controlled system (pneumatic pumps). The controller **80** also can be programmed to determine whether the pump output, as measured by the meter **20**, corresponds to the level of signal **22a**. This information can be used to determine the pump efficiency. It can also be an indication of a leak or another abnormality relating to the pump **18**. Other sensors **94**, such as vibration sensors, temperature sensors may be used to determine the physical condition of the pump **18**. Sensors **S** that determine properties of the wellbore fluid can provide information of the treatment effectiveness of the additive being injected. Representative sensors include, but are not limited to, a temperature sensor, a viscosity sensor, a fluid flow rate sensor, a pressure sensor, a sensor to determine chemical composition of the production fluid, a water cut sensor, an optical sensor, and a sensor to determine a measure of at least one of asphaltene, wax, hydrate, emulsion, foam or corrosion. The information provided by these sensors can then be used to adjust the additive flow rate as more fully described below in reference to **Figure 3** and **4**.

It should be understood that a relatively small amount of additives are injected into the production fluid during operation. Accordingly, rather considerations such as precision in dispensing additives can be more relevant than mere volumetric capacity. Preferably, the flow rate for an additive injected using the present invention is at a rate such that the additive is present at a concentration of from about 1 parts per million (ppm) to about 10,000 ppm in the fluid being treated. More preferably, the flow rate for an additive injected using the present invention is at a rate such that the additive is present at a concentration of from about 1 ppm to about 500 ppm in the fluid being treated. Most preferably the flow rate for an additive injected using the present invention is at a rate such that the additive is present at a concentration of from about 10 ppm to about 400 ppm in the fluid being treated.

As noted above, it is common to drill several wellbores from the same location. For example, it is common to drill 10-20 wellbores from a single offshore platform. After the wells are completed and producing, a separate subsea pump and meter are installed to inject additives into each such wellbore.

Figure 3 shows a functional diagram depicting a system **200** for controlling and monitoring the injection of additives into multiple wellbores **202a-**

202m according to one embodiment of the present invention. In the system configuration of **Figure3**, a separate pump supplies an additive via supply lines **140** from a surface chemical supply **130** (**Fig. 1**) to each of the wellbores **202a-202m**. For example, pump **204a** supplies an additive and the meter **208a** measures the flow rate of the additive into the wellbore **202a** and provides corresponding signals to a central wellsite controller **240**. The wellsite controller **240** in response to the flow meter signals and the programmed instructions controls the operation of pump control device or pump controller **210a** via a bus **241** using addressable signaling for the pump controller **210a**. Alternatively, the wellsite controller **240** may be connected to the pump controllers via a separate line. The wellsite controller **240** also receives signal from sensor **S1a** associated with pump **204a** via line **212a** and from sensor **S2a** associated with the pump controller **210a** via line **212a**. Such sensors may include rpm sensor, vibration sensor or any other sensor that provides information about a parameter of interest of such devices. Additives to the wells **202b-202m** are respectively supplied by pumps **204b-204m** from sources **206b-206m**. Pump controllers **210b-210m** respectively control pumps **204b-204m** while flow meters **208b-208m** respectively measure flow rates to the wells **202b-202m**. Lines **212b-212m** and lines **214b-214m** respectively communicate signals from sensor $\mathbf{S_{1b}}$-$\mathbf{S_{1m}}$ and $\mathbf{S_{2b}}$-$\mathbf{S_{2m}}$ to the central controller **240**. The controller **240** utilizes memory **246** for storing data in memory **244** for storing programs in the manner described above in reference to system **100** of **Figure 1**. The individual controllers communicate with the sensors, pump controllers and remote controller via suitable corresponding connections.

The central wellsite controller **240** controls each pump independently. The controller **240** can be programmed to determine or evaluate the condition of each of the pumps **204a-204m** from the sensor signals $\mathbf{S_{1a}}$-$\mathbf{S_{1m}}$ and $\mathbf{S_{2a}}$-$\mathbf{S_{2m}}$. For example the controller **240** can be programmed to determine the vibration and rpm for each pump. This can provide information about the effectiveness of each such pump.

Figure 4 is a schematic illustration of a closed-loop additive injection system **300** which responds to measurements of downhole and surface parameters of interest according to one embodiment of the present invention. Certain elements of the system **300** are common with the system **150** of **Figur**

2. For convenience, such common elements have been designated in **Figure 4** with the same numerals as specified in **Figure 2**.

The well **118** in **Figure 4** further includes a number of downhole sensors $\mathbf{S_{3a}}$-$\mathbf{S_{3m}}$ for providing measurements relating to various downhole parameters. The sensors may be is located at wellhead over the at least one wellbore, in the wellbore, and/or in a supply line between the wellhead and the subsea chemical injection unit. Sensor $\mathbf{S_{3a}}$ provide a measure of chemical and physical characteristics of the downhole fluid, which may include a measure of the paraffins, hydrates, sulfides, scale, asphaltenes, emulsion, etc. Other sensors and devices $\mathbf{S_{3m}}$ may be provided to determine the fluid flow rate through perforations **54** or through one or more devices in the well **118.** These sensors may be distributed along the wellbore and may include fiber optic and other sensors. The signals from the sensors may be partially or fully processed downhole or may be sent uphole via signal/date lines **302** to a wellsite controller **340**. In the configuration of **Figure 3**, a common central control unit **340** is preferably utilized. The control unit is a microprocessor-based unit and includes necessary memory devices for storing programs and data.

The system **300** may include a mixer **310** for mixing or combining at the wellsite a plurality of **additive #1 - additive #m** stored in sources **313a-312m** respectively. The sources 313a-**312m** are supplied with additives via supply line **140**. In some situations, it is desirable to transport certain additives in their component forms and mix them at the wellsite for safety and environmental reasons. For example, the final or combined additives may be toxic, although while the component parts may be non-toxic. Additives may be shipped in concentrated form and combined with diluents at the wellsite prior to injection into the well **118.** In one embodiment of the present invention, additives to be combined, such as additives **additive #1-additive #m** are metered into the mixer by associated pumps **314a-314m**. Meters **316a-316m** measure the amounts of the additives from sources **312a-312m** and provide corresponding signals to the control unit **340**, which controls the pumps **314a-314m** to accurately dispense the desired amounts into the mixer **310**. A pump **318** pumps the combined additives from the mixer **310** into the wellbore **118**, while the meter **320** measures the amount of the dispensed additive and provides the measurement signals to the controller **340**. A second additive required to be injected into the well **118** may be

stored in the source tank **131**, from which source a pump **324** pumps the required amount of the additive into the well. A meter **326** provides the actual amount of the additive dispensed from the source tank **131**to the controller **340**, which in turn controls the pump **324** to dispense the correct amount.

The wellbore fluid reaching the surface may be tested on site with a testing unit **330**. The testing unit **330** provides measurements respecting the characteristics of the retrieved fluid to the central controller **340**. The central controller utilizing information from the downhole sensors S_{3a}-S_{3m}, the tester unit data and data from any other surface sensor (as described in reference to **Figure 2**) computes the effectiveness of the additives being supplied to the well **118** and determine therefrom the correct amounts of the additives and then alters the amounts, if necessary, of the additives to the required levels. The controller **340** may also receive commands from the surface controller **152s** and/or a remote controller **152s** to control and/or monitor the wells **202a-202m**

Thus, the system of the present invention at least periodically monitors the actual amounts of the various additives being dispensed, determines the effectiveness of the dispensed additives, at least with respect to maintaining certain parameters of interest within their respective predetermined ranges, determines the health of the downhole equipment, such as the flow rates and corrosion, determines the amounts of the additives that would improve the effectiveness of the system and then causes the system to dispense additives according to newly computed amounts. The models **344** may be dynamic models in that they are updated based on the sensor inputs.

The system of the present invention can automatically take broad range of actions to assure proper flow of hydrocarbons through pipelines, which not only can minimize the formation of hydrates but also the formation of other harmful elements such as asphaltenes. Since the system **300** is closed loop in nature and responds to the in-situ measurements of the characteristics of the treated fluid and the equipment in the fluid flow path, it can administer the optimum amounts of the various additives to the wellbore or pipeline to maintain the various parameters of interest within their respective limits or ranges.

Referring now to Figure **5A,** there is shown one embodiment of a surface facility and a remote control station for supporting and controlling the subsea chemical injection and monitoring activities of a subsea chemical injection

system, such as system **150** of **Figure 1**. The Figure **5A** surface facility **500** can provide power and additives as needed to one or more subsea chemical injection units **150 (Fig. 1**). Also, the surface facility **500** includes equipment for processing, testing and storing produced fluids. A one mode surface facility **500** includes an offshore platform or rig or a vessel **510** having a chemical supply unit **520**, a production fluid processing unit **530**, a power supply **540**, a controller **532** and may include a remote controller **533** via a satellite or other long distance means. The chemical supply unit **520** may include separate tanks for each type of chemical desired to be supplied therefrom to the chemical injection unit **150 (Fig. 1)** via a supply line or umbilical bundle **522** that is disposed inside or outside of a riser **550**. Each chemical/additive can either have a dedicated supply line (*i.e.*, multiple lines) or share one or more supply lines. Likewise, the umbilical bundle **522** can include power and/or data transmission lines **544** for transmitting power from the power supply **540** to the subsea components of the system **100** and transmitting data and control signals between the surface controller **532** and the subsea controller **152 (Fig. 1**). Suitable lines **544** include fiber optic wires and metal conductors adapted to convey data, electrical signals and power. The processing unit **530** receives produced fluid from the well head **114 (Fig. 1**) via the riser **550**. Sensors $\mathbf{S_4}$ may be positioned in the chemical supply unit **520**, the production fluid processing unit **530**, and the riser **550** (sensors $\mathbf{S_{4a\text{-}c}}$, respectively). Sensors **S4c** may be distributed along the riser and/or umbilical to provide signals representative of fluid flow, physical and chemical characteristics of the additives and production fluid and environmental conditions. As explained earlier, measurement provided by these sensors can be used to optimize operation of the chemical injection unit **150 (Fig. 1**). It will be appreciated that a single surface facility as shown in **Figure 5A** may be used to service multiple subsea oilfields.

Referring now to **Figure 5B,** there is shown another embodiment of a surface facility. The **Figure 5B** surface facility **600** supplies additives on-demand or on a pre-determined basis to the chemical injection unit **150 (Fig. 1**) without using a dedicated chemical supply unit. A one mode surface facility **600** includes a buoy **610** and a service vessel **630**.

The buoy **610** provides a relatively stationary access to an umbilical **611** and a riser **612** adapted to convey power, data, control signals, and chemicals to

the chemical injection unit **150** (**Fig. 1**). The buoy **610** includes a hull **614**, a port assembly **616**, a power unit **618**, a transceiver **620**, and one or more processors **624**. The hull **614** is of a conventional design and can be fixed, floating, semi-submersed, or full submersed. In certain embodiments, the hull **614** can include known components such as ballast tanks that provide for selective buoyancy. The port **616** is suitably disposed on the hull **614** and is in fluid communication with the conduit **612**. The conduit **612** includes an outer protective riser **612a** and the umbilical **611**, which can include single or multiple tubing **612b** adapted to convey chemicals and additives, power lines **612c**, and data transmission lines **612d**. The power lines **612d** transmit stored or generated power of the power unit **618** to the chemical injection unit (**Fig. 1**) and/or other subsea equipment. The power lines **612d** can also include hydraulic lines for conveying hydraulic fluid to subsea equipment. Power may be generated by a conventional generator **622** and/or stored in batteries **621** which can be charged via a solar power generation system **619**. The transceiver **620** and processors **624** cooperate to monitor subsea operating conditions via the data transmission lines **612d**. The data transmission lines can use metal conductors or fiber optic wires. In certain embodiments, the transceiver **620** and processors **624** can determine whether any subsea equipment is malfunctioning or whether the chemical injection unit **130** (**Fig. 1**) will exhaust its supply of one or more additives. Upon making such a determination, the transceiver **620** can be used to transmit this determination to a control facility (not shown). Sensors $\mathbf{S_5}$ may be positioned in the production fluid processing unit **640** (sensor $\mathbf{S_{5a}}$), the riser **612** (sensor $\mathbf{S_{5b}}$), or other suitable location. As explained earlier, measurement provided by these sensors can be used to optimize operation of the chemical injection unit **130** (**Fig. 1**). The subsea chemical injection unit can be sealed in a water-tight enclosure.

The service vessel **630** includes a surface chemical supply unit **632** and a suitable equipment (not shown) for engaging the buoy **610** and/or the port **616**. The service vessel **630** may be self-powered (*e.g.*, a ship or a towed structure). During deployment, the service vessel **630** visits one or more buoys **610** on a determined schedule or on an as-needed basis. Upon making up a connection to the port **616**, one or more chemicals is pumped down to the chemical storage tank **130** (**Fig. 1**) via the tubing **612b**. After the pumping operation is complete, the buoy **610** is released and the service vessel **630** is free to visit other buoys

610. It should be appreciated that the buoy **630** according to the present invention are less expensive than conventional offshore platforms.

Produced fluid from the well head **114** (**Fig. 1**) is conveyed via a line **632** to a fluid processing unit **640**. The processed produced fluids are then transferred to a surface or subsea collection facility via line **642**.

Referring to **Figure 1, 5A** and **5B,** the system may further include devices that heat production fluid in subsea lines, such as line **127**. The power for heating devices (**189**) can be tapped from power supplied by the surface unit to the subsea chemical injection unit **150** or to any other subsea device, such as wellhead valves. The sensors **S** monitor the condition of the production fluid. The system of **Figures 1-5** controls and monitors the injection of chemicals into subsea wellbores **118.** A subsea chemical injection alone can control and monitor the injection of chemicals into wellbores **118** and underwater processing facility **126.** The system can also monitor the fluid carry lines **127**. The unit **150** can control and monitor the chemical injection in response to various sensor measurements or according to programmed instructions. The chemical sensor in the system provides information from various places along the wellbore **118,** pipe**127**, fluid processing unit **126**, and riser **124** or **150**. The other sensors provide information about the physical or environmental conditions. The subsea controller **152**, the surface controller **152s** and the remote controller **152s** cooperate with each other and in response to one or more sensor measurements in parameters of interest control and/or monitor the operation of the entire system shown in **Figs. 1-5**.

While the foregoing disclosure is directed to the one mode embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.